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November 1989

2-kW DC Instantaneous Uninterruptible Power Supply Description

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ADMINISTRATIVE INFORMATION

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13. ABSTRACT (Maximum 200 words) A 2-kW uninterruptible power supply was designed, built, and tested to demonstrate the feasibility of using uninterruptible power supplies (UPSs) to sustain critical loads onboard U. S. Navy ships. Performance requirements were met or exceeded. The design approach is modular and is shown to be expandable from its present 2-kW implementation to 10-kW or more. Implementation would be on Navy ships being newly constructed.					
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SUMMARY

OBJECTIVE

The objective of this report is to demonstrate the feasibility of using dc uninterruptible power supplies (UPSs) to sustain critical loads onboard U. S. Navy ships.

RESULTS

A 2-kW demonstration UPS was designed, built, and tested. Performance requirements were met or exceeded.

RECOMMENDATIONS

Consider the UPS and the overall power system approach — which it is part of — for new construction Navy ships.

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INTRODUCTION

This document describes and gives the test results for a 2-kW uninterruptible power supply (UPS). The hardware was built to demonstrate a new approach to shipboard power conditioning, with the UPS as one of the three major components of this shipboard power conditioning system.

The basis for this approach to shipboard power conditioning can be appreciated by considering figure 1 and noting these important points. The prime power is still conventionally generated and distributed as 440-volt, 60-Hz, 3-phase power. However, an essentially ideal ac-to-dc interface exists at the individual compartment level. This interface provides 155-Vdc power to equipment within the compartment. The 155-Vdc results from rectifying 115-Vac, 3-phase power. Much existing equipment will operate from either of these voltages, and, in addition, the interface also possesses the characteristics of an ideal ac-to-dc interface. These features include rectifying to dc, while meeting the 3-percent harmonic current limit; providing spike protection; limiting surge current; providing either short- or long-term energy storage, as required for prime power interruption; limiting input voltage harmonics; and providing the above capabilities with almost 100-percent efficiency.

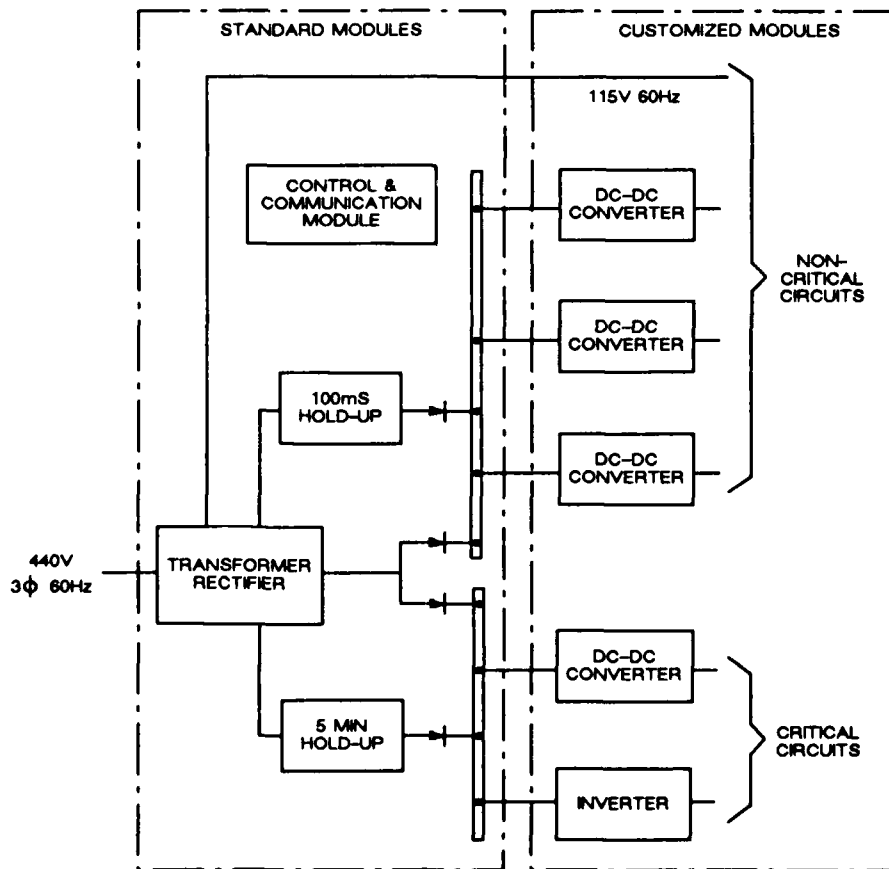


Figure 1. Overall power system, block diagram.

Present shipboard power systems lack many capabilities. Currently, very little is done to provide short- or long-term energy storage. When power is interrupted to critical Navy shipboard loads, frequently there is a long restart requirement, a loss of critical information, or a loss of offensive or defensive capability. Continuity of power to these loads can be critical to a ship's survival in a war-time situation.

This technical document shows that it is feasible for the UPS to provide power to these critical loads during the time it takes to restart or redirect electrical power after loss onboard ship. The UPS will provide a minimum of 5 minutes of power to a 2-kW load. The feasibility of shipboard UPS is clearly demonstrated with this hardware.

UPS REQUIREMENTS

These are the requirements for the UPS:

Power: 2-kW output

Time: 5 minutes, minimum

Output Voltage Range: 155 V to 108 V, minimum

Input Voltage: 155 Vdc, nominal

Power Recovery from Interruption: Instantaneous

Modular Design

Expandable in Design Approach from 2 kW to 10 kW

Efficiency: 98 percent

GENERAL DESCRIPTION AND CIRCUIT OPERATION

The 2-kW UPS shown in figure 2 shows the feasibility of storing energy for critical loads. The approach is modular and expandable to higher power levels from the present 2-kW implementation to 10 kW or more. The hold-up circuit consists of four basic subassemblies. These subassemblies are the hybrid power transfer switch, the battery charging circuitry, the battery test circuitry, and the status monitoring circuitry. Figure 3 is a basic block diagram of the hold-up circuit.

The hybrid transfer switch is shown in figure 4. Note that the FETs in series with the zener diodes are normally on. This means that should the load voltage drop below the battery voltage, minus the zener diode breakdown voltage, the zeners will conduct, and power will be supplied to the load. This happens instantaneously, without interruption, even if the load's line voltage disappears rapidly. Conduction through the zeners is inefficient, so sensing circuitry turns on the FETs in parallel with the zeners, effectively removing them from the conduction path. This switch arrangement is the normal condition for UPS operation until the output voltage

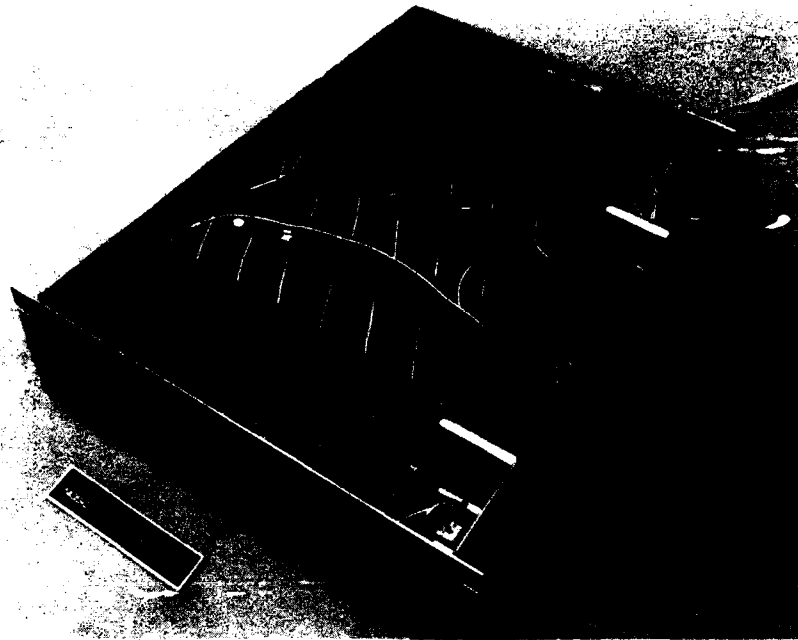


Figure 2. The 2-kW demonstration UPS.

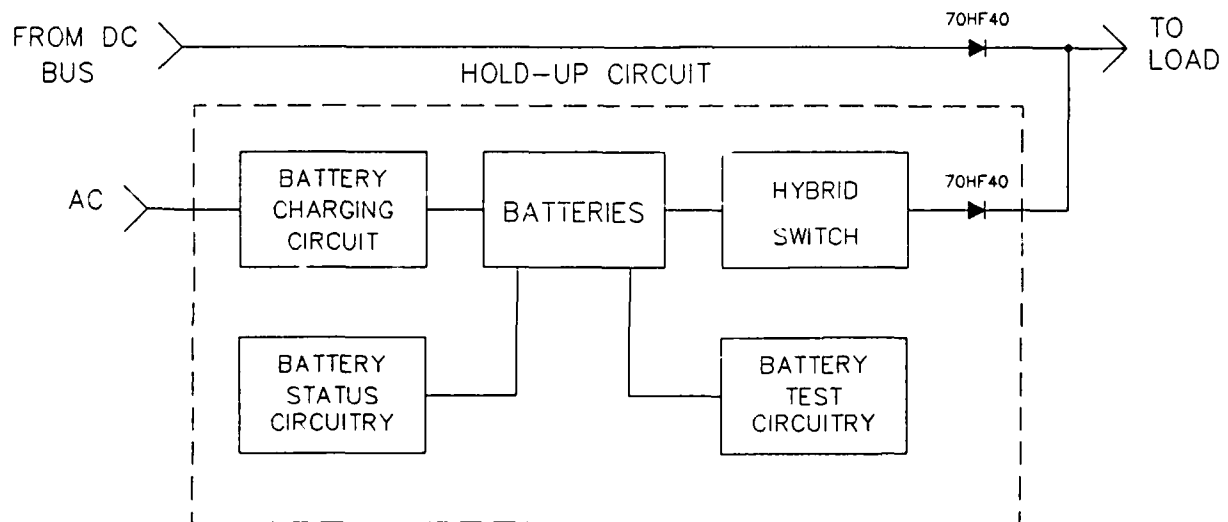
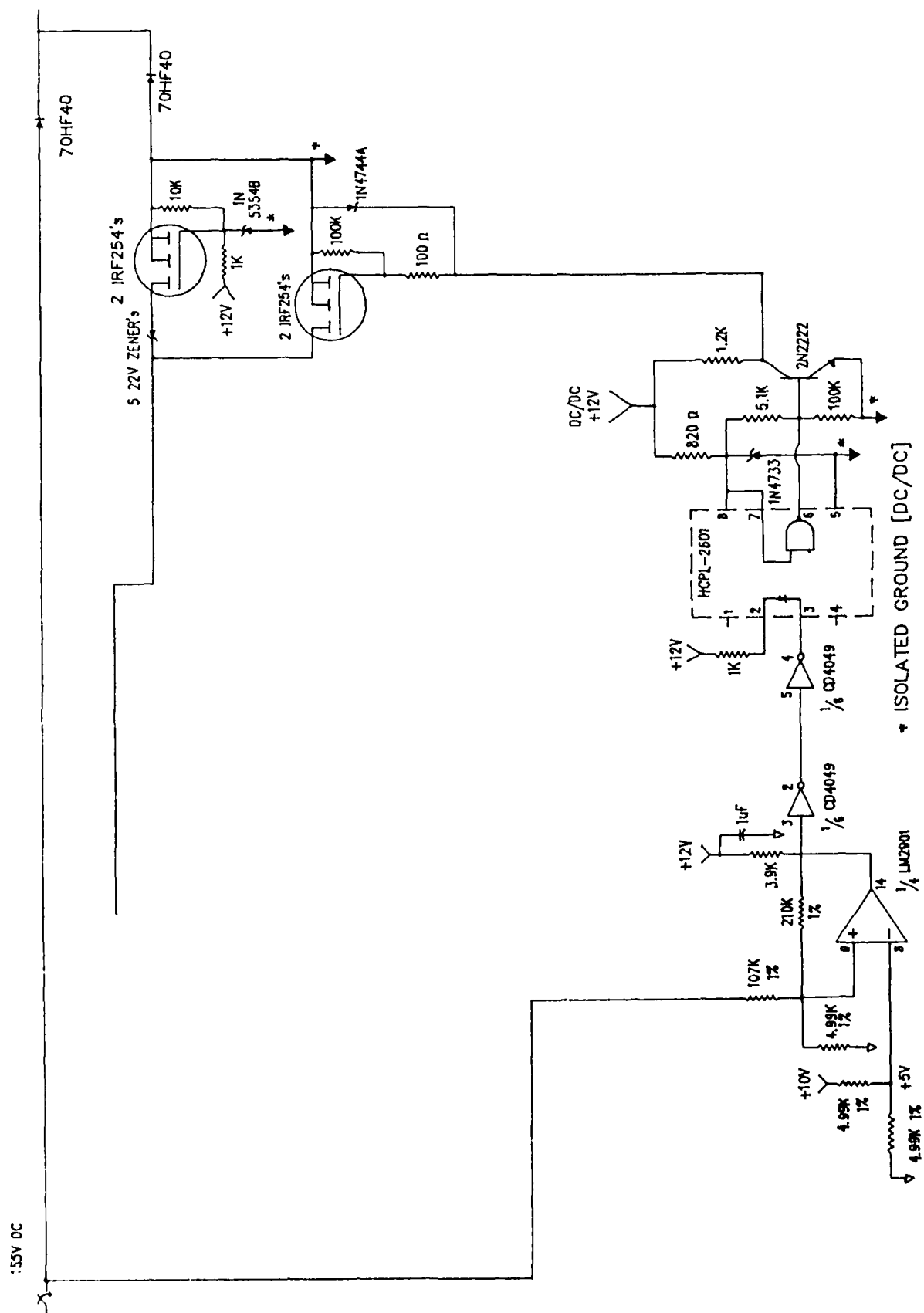


Figure 3. The 2-kW UPS, block diagram.



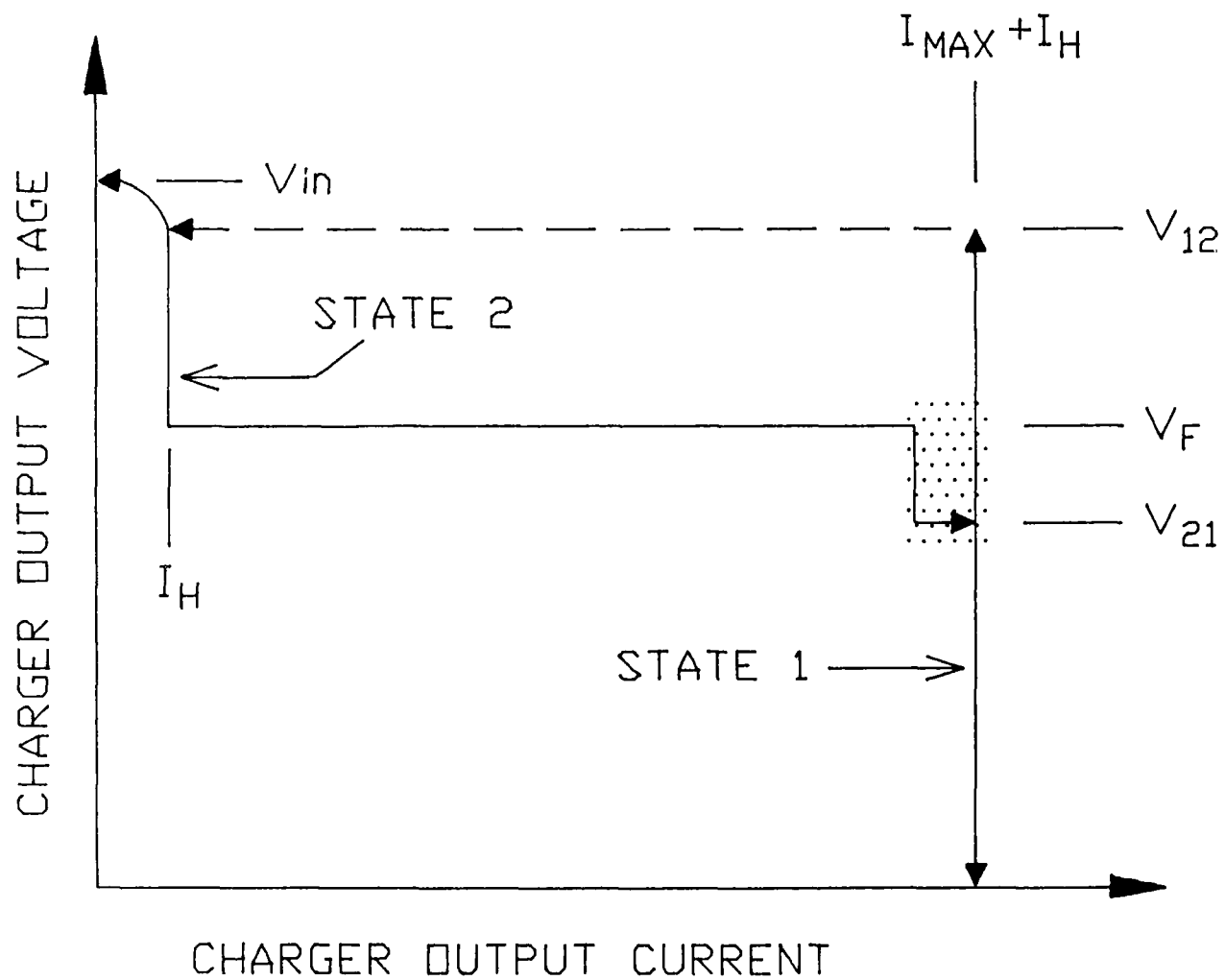
reaches the lower limit of 108 volts. At this time, other sensing circuitry opens both pairs of FETs, stopping power to the loads past the lower voltage limit and preventing damage to the batteries by completely discharging them.

Figure 5 describes the operation of the battery charging circuitry. A Unitrode UC 3906 integrated circuit (IC) is employed to construct a two-state battery charger. The circuit permits a high constant-current charge when the batteries are heavily discharged. This is the state 1 or bulk current charge for the charger. The bulk charge continues until voltage V_{12} is reached, at which time the charger reverts to state 2 (a constant-current holding state). This dual-state current charger approach has several advantages. Instead of employing an elevated constant-voltage over-charge, the charger switches to the constant-current holding state. This prevents overcharging the batteries, which can shorten their lifetimes. Also, for a large series number of batteries, the current charger has advantages, since the voltage across a large series number of cells is not as predictable as across a common three- or six-cell string. In standby service, varying self-discharge rates can significantly alter the state of charge of the individual cells in the string if a constant float voltage is used. The elevated voltage, low-current holding state of the dual-step current charger attempts to maintain a full and equal charge on the cells. Figure 6 shows the overall schematic for the battery-charging circuitry.

The input battery charge voltage is critical to charger operation and selection of the number of batteries employed in the UPS. The input voltage is the nominal 155 Vdc from the polyphase transformer rectifier system as described in NOSC TD 1535. Because of transformer droop characteristics (output voltage dropping with increasing load current), the input voltage the UPS will normally have is 148 to 141 volts. If a nominal ± 5 -percent variation of these voltages is assumed, as shown in figure 7, the worst case voltage the charger will have to charge from is 134 Vdc. This voltage is critical to the battery charger design and sets a limit on the number of series voltage cells permitted.

The battery charger circuitry does have several shortcomings, however. One is that it is unable to charge off of a 134-volt input line. The other is that because the UC 3906 IC is floating at essentially the 148-volt input, various transient conditions leave the chip prone to failure. Most of these conditions have been dealt with, however reliability of the battery charger is still an issue. These matters were discovered too late in the design cycle to change. However, a custom design battery charger should be considered if the 2-kW UPS is to be upgraded.

For operation of battery test circuitry, see figure 8. A test of battery capacity is initiated by pushing the battery test button. This action provides an input for the test cycle to start for the NE556 timer which provides a 7.5-second gate drive. The gate drive that this IC initiates eventually turns on the two IRF254s which are in series with the 2-kW test load. Full battery power is then dumped into this test load, causing the battery voltage to slowly drop. A comparator measures the amount of voltage drop and compares it to a reference. This action is done 7 seconds (initiated by the 7-second status timer) into the 7.5-second test period. Depending on whether the battery voltage measured is above or below the reference value, the low or normal



STATE 1:
BULK CHARGE

STATE 2:
HOLDING CHARGE

Figure 5. State diagram for the dual-step current charger.



LOAD KW	-5%	NOMINAL	+5%
0	141	148	155
2.5	139	146	153
5.0	138	145	152
10	134	141	148

CONCLUSION:
 BATTERY CHARGER MUST BE CAPABLE
 OF CHARGING BATTERIES OFF 134 VDC
 OUTPUT.

Figure 7. 2-kW UPS battery charger voltages.

155V DC

70HF40

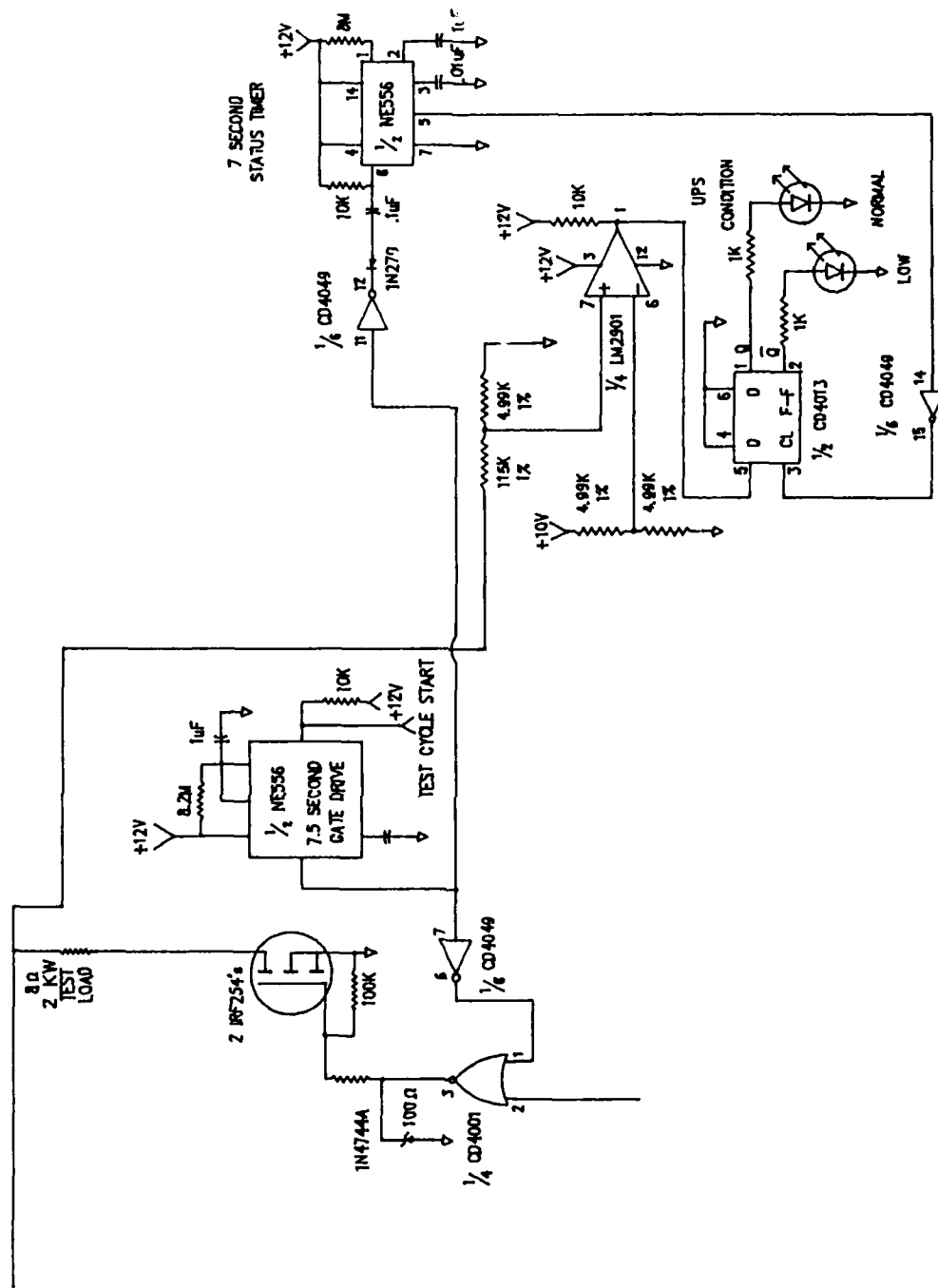


Figure 8. UPS battery test circuitry.

UPS condition lights are activated. Normally, unless the batteries have been recently discharged, the voltage will be above the reference, so a low battery indication means a defective cell or cells.

The status monitoring circuitry comprises the rest of the UPS system. The overall schematic (figure 9) shows LED or light indicators with a "DC Bus ON" light at the input to the UPS. Next, if the Bus voltage falls below the lower voltage limit of 109 volts, the UPS will pick up the load and the "UPS IN USE" LED will illuminate. The remaining three LEDs and lights are associated with the UPS battery test circuitry. Upon pressing the UPS test button, the "UPS IN TEST" light will illuminate. If an actual drop in input power occurs at this time, the circuitry will cancel the test and immediately pick up the load.

Under normal conditions, however, full battery power will flow through an 8-ohm, 2-kW test load, as previously described, and either the UPS condition "Low" or "Normal" LED will illuminate.

CONSTRUCTION

Figure 10 shows the wiring layout for the demonstration 2-kW dc UPS. The numbers associated with each wire should be useful during maintenance or testing. Figure 11 is a parts list for the UPS.

EXPERIMENTAL RESULTS

The experimental results for the UPS are shown in figures 12 through 14. Figure 12 shows the UPS switch transfer characteristics. Continuous power is delivered to the load when input power is interrupted. Figure 13 shows the temperature-dependence characteristics of the batteries; note that with lower temperatures, the battery output drops significantly. Figure 14 shows the effect of one complete battery (3 cells) failing and that 5 minutes of power is still available before the voltage drops below 109 volts.

CONCLUSIONS

The feasibility of this straightforward approach to shipboard UPS has been demonstrated, with only two concerns apparent. One involves the battery charger circuit which should be redesigned if time and resources permit. A custom battery charger circuit could provide higher reliability and the ability to charge off lower line voltages. The second concern is that an unequal charge condition may develop with time because of the large number of batteries in series (21 in this case). Further testing should demonstrate whether or not this is a valid concern. Overall, the 2-kW UPS developed here does show that the approach is practical and can be implemented on Navy ships being newly constructed.

2 KW HOLD-UP CIRCUIT

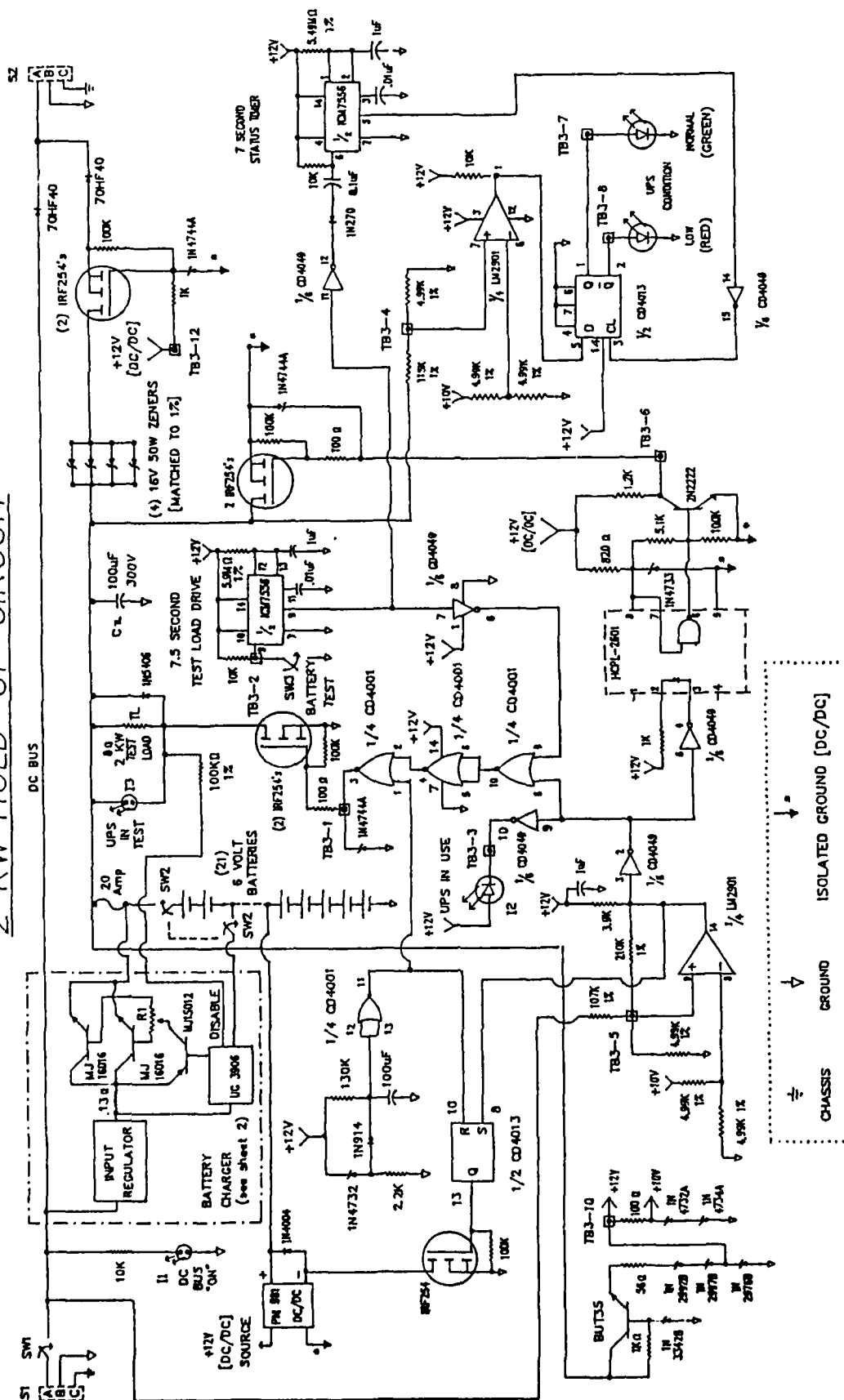


Figure 9. Complete UPS schematic.

2 KW HOLD-UP CIRCUIT WIRING DIAGRAM

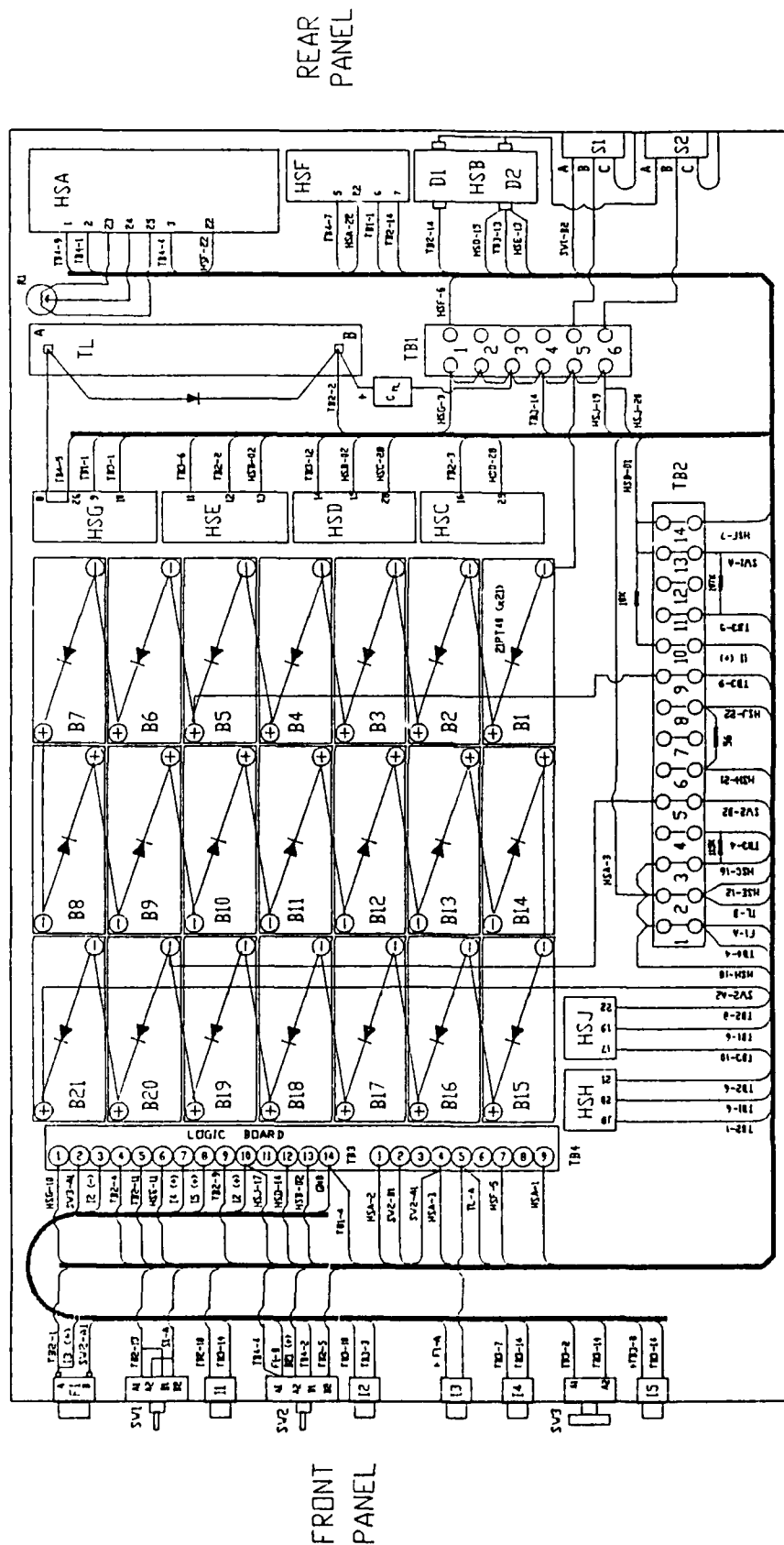


Figure 10. Demonstration UPS, wiring connection diagram.

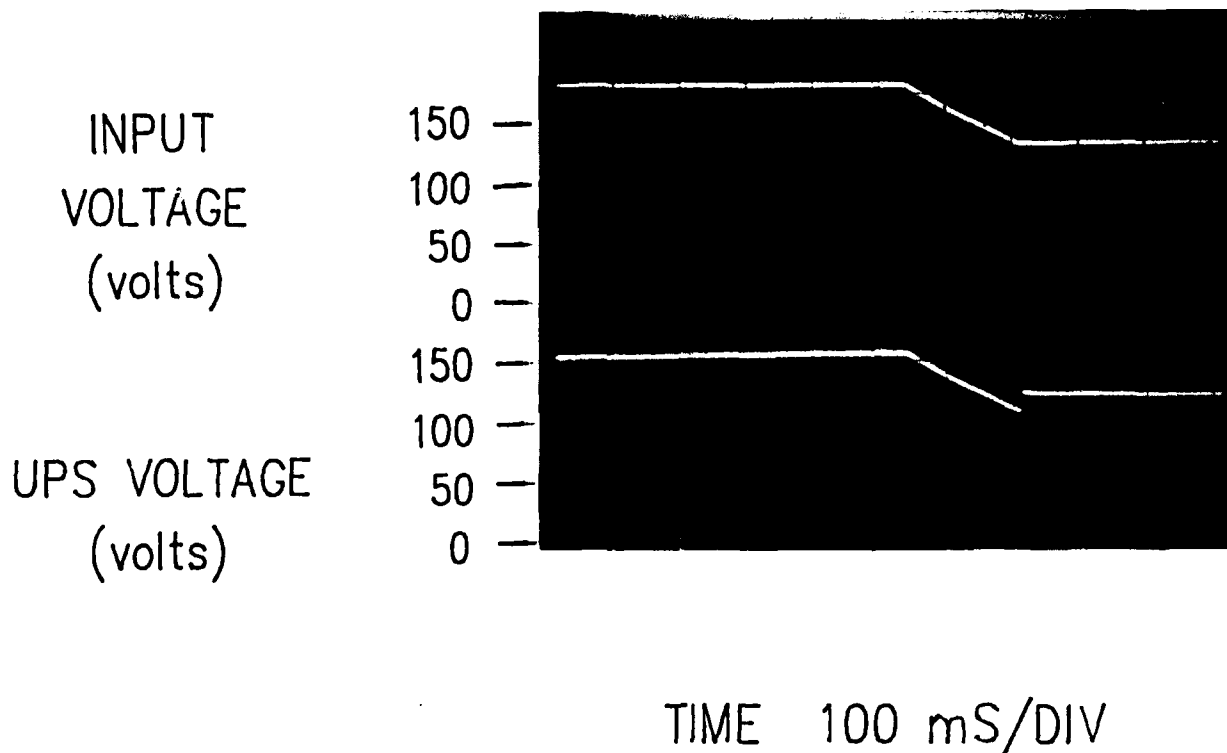
ITEM	DESCRIPTION	TYPE/VALUE/P/N	MFG.	QTY
1	RESISTOR	10 OHM, 1/4W, 5%	ANY	2
2	"	100 OHM, 25W, WW (WIREWOUND)	ANY	1
3	"	220 OHM, 1/4W, 5%	ANY	2
4	"	500 OHM, 100W, WW L100J500	OHMITE	1
5	"	1K OHM, 1/4W, 5%	ANY	1
6	"	1K OHM, 100W, WW L100J1K0	OHMITE	1
7	"	1.5K OHM, 50W, WW 850F1K5	OHMITE	1
8	"	2K OHM, 5W, WW	ANY	1
9	"	4.99K OHM, 1/4W, 1%	ANY	4
10	"	10K OHM, 1/4W, 5%	ANY	5
11	"	10K OHM, 5W, WW	ANY	1
12	"	10K OHM, 11W, WW 90J10K	OHMITE	1
13	"	20K OHM, 11W, WW 90J20K	OHMITE	1
14	"	20K OHM, 1/4W, 5%	ANY	1
15	"	100K OHM, 1/4W, 5%	ANY	4
16	"	115K OHM, 1/4W, 0.25%	ANY	1
17	"	200K OHM, 1/4W, 1%	ANY	1
18	"	218K OHM, 1/4W, 0.25%	ANY	1
19	"	1MEG OHM, 1/4W, 5%	ANY	1
20	"	2.2MEG OHM, 1/4W, 5%	ANY	1
21	CAPACITOR	100pF, 50V, CERAMIC	ANY	1
22	"	0.01uF, 50V, CERAMIC	ANY	1
23	"	1uF, 50V, CERAMIC	ANY	2
24	CAPACITOR, ELECTROLYTIC	10uF, 25V	ANY	2
25	"	6300uF, 250V, 36DX832F250DF2A	SPRAGUE	12
26	"	51,000uF, 40V, 36DX513G040CF2A	SPRAGUE	1
27	DIODE	1N4004	ANY	2
28	"	1N5406	ANY	6
29	"	1N5819	ANY	2
30	"	85HF80	INTERNATIONAL RECTIFIER	2
31	"	1N4733A	MOTOROLLA	2
32	"	1N4735A	MOTOROLLA	2
33	"	1N4737A	ANY	1
34	"	1N4744A	ANY	2
35	"	Z23ZA34.5A	INTERNATIONAL RECTIFIER	1

Figure 11. 2-kW UPS parts list.

[illegible]

Figure 11. 2-kW UPS parts list (continued).

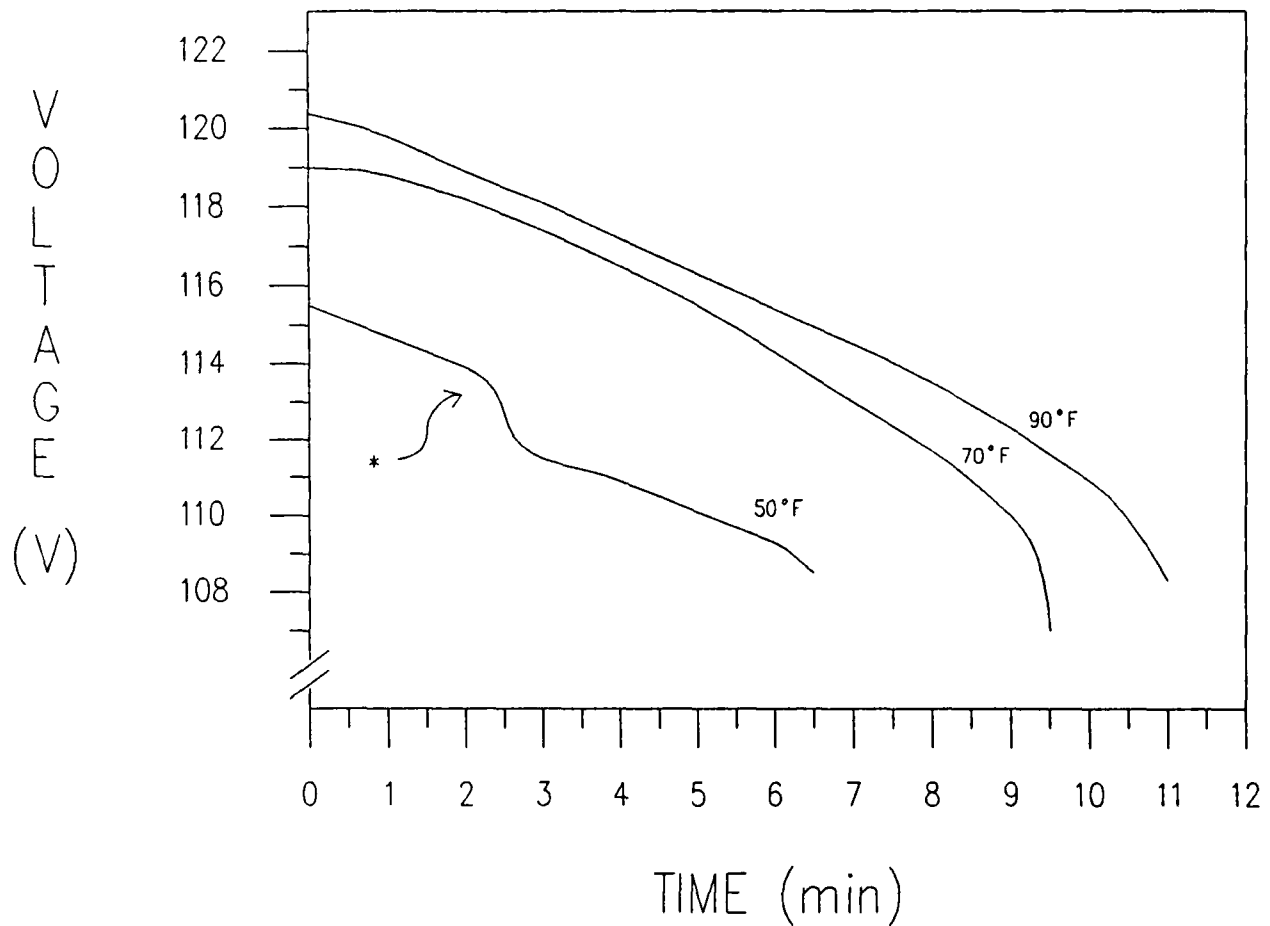
2-KW UPS OPERATION DURING POWER LOSS



Note : Input voltage during test is from HP supply. Due to characteristics of supply voltage, it does not decay rapidly to zero when power is removed.

Figure 12. 2-kW UPS switch transfer characteristics.

DISCHARGE VOLTAGE vs. TIME



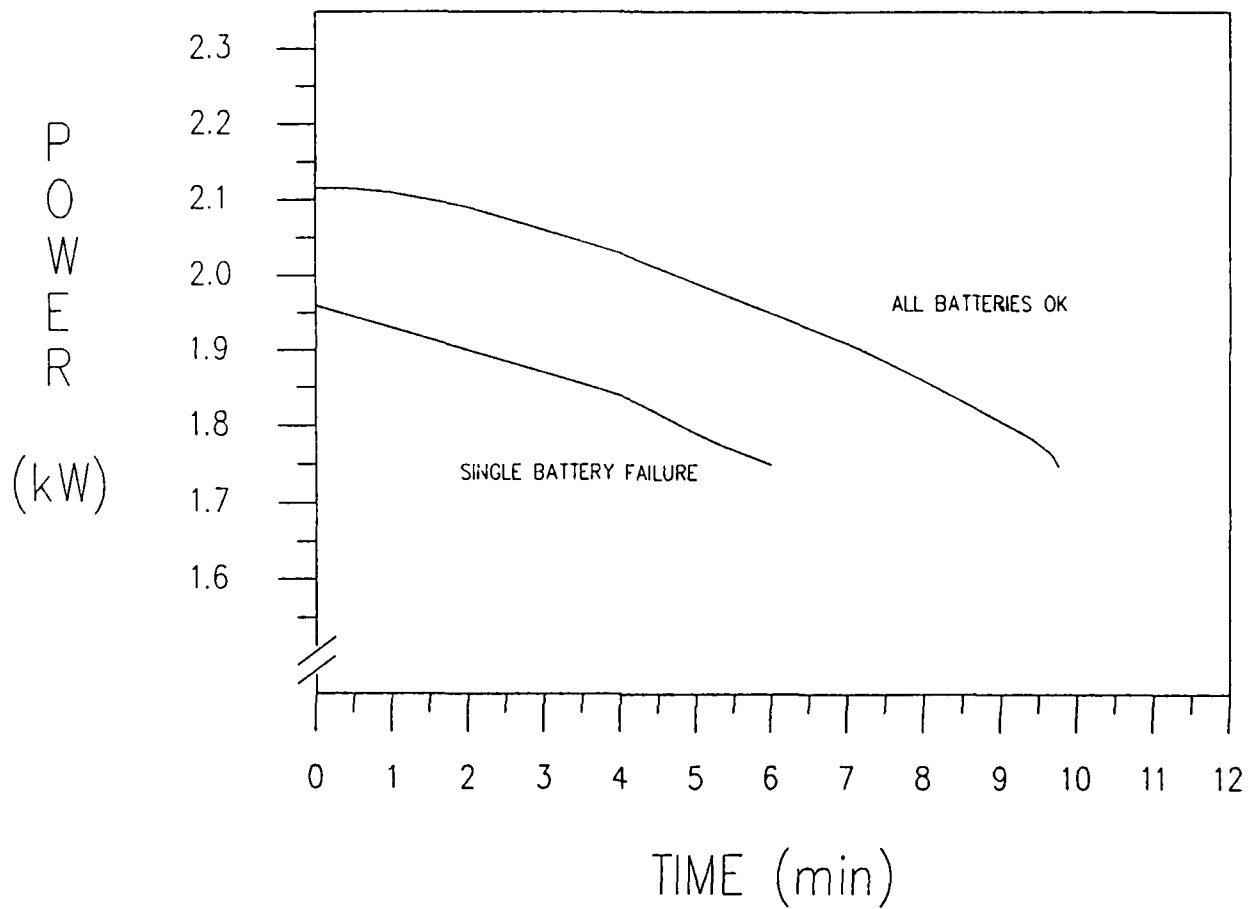
LOAD = 6.7Ω

BUS CHARGING VOLTAGE = 141V

* SINGLE-CELL FAILURE IN ONE BATTERY

Figure 13. 2-kW UPS battery discharge voltage vs. time.

BATTERY FAULT TEST



LOAD = 6.7Ω

TEMPERATURE = 70°F

BUS CHARGING VOLTAGE = 141V

Figure 14. 2-kW UPS single battery failure, power vs. time.